REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate only, other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (07804-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(LEAVE BLANK)*	2. REPORT DATE 5 April 1999	3. REPORT TYPE AND DATES COVERED Professional Paper

4. TITLE AND SUBTITLE

Adaptation of a Ground Proximity Warning System for Rotorcraft

5. FUNDING NUMBERS

6. AUTHOR(S)

Maj Doug Schueler, USMC   John Durkin   Rick Funchion

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Air Warfare Center Aircraft Division
22347 Cedar Point Road, Unit #6
Patuxent River, Maryland 20670-1161

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Air Systems Command
47123 Buse Road, Unit IPT
Patuxent River, Maryland 20670-1547

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Ground Proximity Warning Systems have experienced considerable success as a safety backup device for fixed wing aircraft applications. Transferring this concept to a Rotorcraft, however, requires compensation for a type of aircraft that is intentionally flown at low altitudes, relatively slow airspeeds, and in most cases, provides no definitive cues as it transitions to a landing or hovering state. NAVAIRSYSCOM has chosen a system for selected helicopters in the Navy and Marine Corps inventory which has shown considerable promise during developmental and operational testing. The system incorporates a predictive warning algorithm that issues warnings based on the dynamic state of the aircraft rather than fixed altitudes alone. Other available features include a pilot-selectable altitude warning, as well as warnings for excessive bank angle, gear-up landing, tail strike, descent below ILS glide slope, and altitude loss immediately after takeoff.

14. SUBJECT TERMS

Ground Proximity Warning System (GPWS)   Rotorcraft

15. NUMBER OF PAGES

7

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

Adaptation of a Ground Proximity Warning System for Rotorcraft

Maj Doug Schueler, USMC
CH-46E Test Pilot
Naval Air Warfare Center
Patuxent River, Maryland

Mr. John Durkin
GPWS Engineer
Cubic Defense Systems
San Diego, California

Rick Funchion
Flight Test Engineer
Naval Air Warfare Center
Patuxent River, Maryland

Abstract

Ground Proximity Warning Systems have experienced considerable success as a safety back-up device for fixed wing aircraft applications. Transferring this concept to a Rotorcraft, however, requires compensation for a type of aircraft that is intentionally flown at low altitudes, relatively slow airspeeds, and in most cases provides no definitive cues as it transitions to a landing or hovering state. The Naval Air System Command has chosen a system for selected helicopters in the Navy and Marine Corps inventory which has shown considerable promise during developmental and operational testing. The system incorporates a predictive warning algorithm which issues warnings based on the dynamic state of the aircraft rather than fixed altitudes alone. Other available features include a pilot selectable altitude warning, as well as warnings for excessive bank angle, gear-up landing, tailstrike, descent below ILS glideslope, and altitude loss immediately after takeoff.

Introduction

A Ground Proximity Warning System (GPWS) is an airborne system used to provide timely warnings to pilots and aircrew to prevent or reduce the occurrence of Controlled Flight Into Terrain (CFIT) incidents. CFIT is defined as a "Mishap that occurs when an aircraft is mechanically sound, capable of normal flight, the pilot is not disabled and the aircraft is inadvertently flown into the ground or water."(Ref. 1) Factors contributing to CFIT include the following:

Pilot Distraction
Inattention
Disorientation
Fatigue
Optical Illusions
Loss of Situational Awareness

Ground Proximity Warning Systems have received considerable recent publicity as a safety enhancement system for both commercial and military fixed wing aircraft. Applying GPWS principles to a rotary wing application presents an array of formidable challenges. One of the prime difficulties encountered when transferring GPWS principles to a helicopter is how to provide timely and accurate ground closure warning cues for an aircraft which spends a majority of its flight profile operating in close proximity to the ground. This is especially true for military helicopters that may spend an entire mission flight profile in the Terrain Flight (less than 200 ft AGL) mode. Another significant difficulty with rotorcraft, even those with retractable landing gear, is that there is often no clear configuration change or definition of an intended terminal state, i.e. transition to a hover or landing, where a warning of impending ground closure is not necessary and in most cases undesirable.

The current effort to incorporate a GPWS in Naval Aircraft stemmed from an Operational Requirement approved by the Chief of Naval Operations (CNO) in 1987 and re-emphasized in a recent 1998 CNO directive (Ref. 2). This requirement, as applied to the helicopter flight profile, called for GPWS to be operational and provide CFIT protection during takeoffs and landings, enroute cruise, ship approaches, vertical replenishment, search and rescue, anti-submarine warfare, hover, and autorotation in the form of tailstrike warnings. The system was required to provide protection for the following unsafe flight conditions:

Excessive Descent Rate
Excessive Terrain Closure
Altitude Loss Following Takeoff
Descent Below Minimum Altitude
Gear-up Landing
Excessive Bank Angle or Pitch Attitude (Tailstrike)
Deviations Below the ILS Glideslope

Accident investigations have shown that the probability of CFIT increases when an aircraft is maneuvered at low altitudes, particularly at night or in less than optimum weather conditions. Radar altimeters and Low Altitude Warning Systems (LAWS) alone do not provide a predictive capability to warn against CFIT situations, and high workload situations can distract pilots or crew from monitoring aircraft ground clearance. Conventional, warning based, GPWS systems issue warnings at relatively higher AGL altitudes resulting in an unacceptable nuisance alarm rate for rotary wing aircraft. With an ever increasing pilot workload and need to perform complex low-level missions, systems that provide predictive and directive warnings can assist pilots in recovering from potential CFIT situations (Figures 1 and 2).
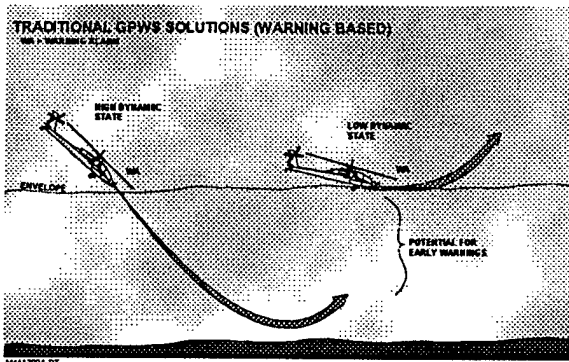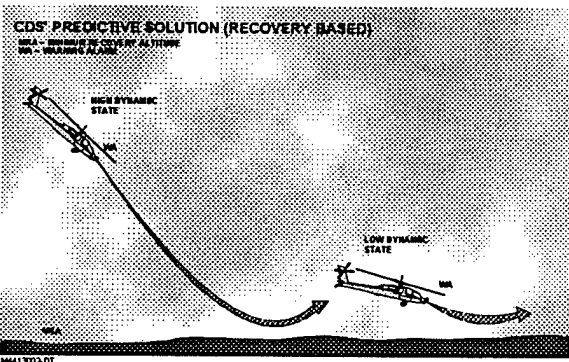

Figure 1 – Traditional GPWS Warnings

Figure 2 – Predictive GPWS Warnings

This paper will focus on the Predictive or Recovery Based Solution GPWS (copyright Cubic Defense Systems, Inc. 1991-1999) developed to fulfill the 1987 CNO GPWS requirement through a joint effort by the Naval Air Warfare Center, Aircraft Division and Cubic Defense Systems, Inc. The basic system used for this effort was a commercial off the shelf (COTS) item, adapted to protect aircraft performing various Naval helicopter missions. Practical experience was gained while the system was integrated and tested on the Marine Corps' CH-53 and CH-46E helicopters and the Navy's MH-53E minesweeper variant.

GPWS Development

The general architecture of GPWS was designed such that it would be applicable for a generic helicopter's mission profile. The system's software contains aircraft type specific performance modules to determine warning states for each individual aircraft. The operational mission of each particular aircraft dictated the standards and requirements for which the GPWS was designed and tested. The mission of both the CH-53 and CH-46 helicopters involve the tactical movement of personnel and cargo, both internally and external, however, fundamental airframe and performance differences dictated that the GPWS be specifically tailored for each aircraft in certain areas. Within the mission requirements of both aircraft, and most military helicopters in general, are operations at low level altitudes, both day and night, and operations under instrument meteorological conditions or adverse weather. The operational profile also extends to operations to and from prepared and unprepared remote landing sites, and to and from air capable ships or even gas/oil platforms at sea. Additionally, since the system was being integrated into mature airframes, concern existed to minimize overall weight addition to the airframe and take maximum advantage of pre-existing aircraft system inputs. This was in contrast to an alternative strategy of incorporating heavy and/or complicated systems such as a terrain following radar.

One underlying requirement of GPWS that makes it a true safety enhancing system was that it had to be continuously running behind the scenes as the aircraft carried out its operational mission, thus not able to be selected or de-selected by the pilot. To be a system that would reduce the occurrence of CFIT incidents, the warnings issued by the system must be directive to bring pilot attention to the immediacy of the situation, and accurate in the timeliness of their issuance. Critical to the credibility of the system is the absence of nuisance or false warning cues, which over time would lead pilots to second guess or ignore warnings. This required the system to define the difference between a condition where the aircraft was likely to impact the ground, or merely an ordinary flight profile

such as entering a normal approach flight path to a landing or hover, enroute terrain following flight at low altitudes, or crossing the deck edge aboard an air capable ship.

At the heart of the GPWS capabilities is the system's predictive recovery based warning cues. The Cubic Defense Systems, Inc. patented predictive warning algorithm was designed to compute the altitude the aircraft would lose from the time a warning is issued, until cancellation of terrain closure and a positive rate of climb could be established, based on a maximum power application. This predicted value is referred to as the Predicted Altitude Loss or PAL. The PAL is a constantly changing value based on the aircraft's current in air dynamic state (G-loading, rate of descent, airspeed, angle of bank, etc.) and the underlying terrain trend. The PAL is continuously compared with the aircraft's actual height over ground, and when the height over ground becomes equal to or less than the PAL, an appropriate warning is issued.

System Description

The system consists of a single ¼ ATR Short, 8 lb., Ground Proximity Warning Computer (GPWC), that interfaces with other aircraft systems to collect required inputs. The inputs are provided to the GPWC using discrete wire interconnections to the individual sensors, via a 1553 data bus, or a combination of the two methods. The primary external sensor to the system is the radar altimeter. This is used not only to provide accurate height above ground level, but also to allow a constant calculation of the closure rate with the ground. Normal acceleration for the GPWS is obtained using an accelerometer installed within the GPWC. Other system inputs that were utilized include the aircraft's attitude and rate gyros, engine torque, Weight on Wheels (WOW), landing gear (on retractable systems only), localizer and glideslope receivers, and air data. An Air Data Computer (ADC) was installed in both the CH-46E and H-53's to provide the GPWC and other aircraft systems with more accurate air data. The ADC provides the GPWC with indicated airspeed, true airspeed, pressure altitude, temperature, and vertical speed. All GPWS data sources are sampled at 10Hz. This frequency was needed to provide a clear resolution of the dynamics of the aircraft and be able to provide a timely warning to the pilot in case of a potential CFIT.

Predicted Altitude Loss

The most difficult part of integrating a GPWS into a helicopter is accurately determining when to give the pilot a warning to initiate a recovery just in time to avoid a CFIT. Since the helicopter works relatively close to the ground, large safety buffers or approximations are inadequate. They result in warnings that mean that the aircraft is operating close to the ground, completely under control, and not that the pilot must take corrective measures immediately. These cues become a large nuisance to the pilots, result in a loss of credibility with the GPWS warnings, and the end result is very little extra protection. The Predictive or Recovery Based GPWS Solution achieves a much higher warning accuracy level than earlier, conventional GPWS systems by continually calculating the altitude loss that would occur if a pilot initiated a recovery at that particular instant. The algorithm uses inputs from the aircraft to determine its dynamic state and then uses aircraft specific performance figures to determine how quickly a pilot could recover the aircraft. This calculation is performed ten times every second. When the algorithm calculates that the aircraft has less altitude than it would take to arrest the closure with the ground the aural warning "WHOOP WHOOP PULL UP PULL UP " is given.

Total Predicted Altitude Loss (PAL) during a recovery can conceptually be divided into three distinct elements which are then summed together. In reality, all three of the elements of PAL are computed using a single iterative numerical integration within the GPWS Algorithm.

The first element of the altitude loss calculation is pilot/aircraft response time. From the time the CFIT warning is issued until the flight controls start to move, the aircraft may lose a significant amount of altitude. A constant is used which assumes the pilot/aircraft response time will be 1.5 seconds. This response time was derived after significant simulator and flight testing was performed to measure the pilot's response to the voice warnings, and using instrumented aircraft flight controls to identify when they begin to move. Altitude loss attributable to response time (H_{pr}) can be described as function of:

$$H_{pr} = f(\tau, Vz, \Delta AzN, TC, TD)$$

where:

$$\tau \equiv \text{Response Time Constant}$$
$$Vz \equiv \text{Barometric Vertical Velocity}$$
$$\Delta AzN \equiv \text{Rate of Change of Normal Acceleration}$$
$$TC \equiv \text{Terrain Closure Rate}$$
$$TD \equiv \text{Terrain Dampening Factor}$$

The 1.5 second response time constant was selected so as to achieve the optimum altitude loss estimate over wide ranges of aerodynamic conditions and differing underlying terrain conditions. It was found that setting the response time constant below 1.0 seconds resulted in an unacceptable crash statistic and going above 1.5 seconds increased nuisance warnings at an exponential rate. The final value selected, delivered the maximum amount of protection without an unacceptable level of nuisance alarms.

The second element of the altitude loss calculation is the determination of how much altitude will be lost rolling wings level (H_{rr}), if the aircraft is banked. The algorithm uses an aircraft type specific roll rate equation that is a function of the Initial Roll Angle, the Barometric Vertical Velocity, and the Normal G-Loading of the aircraft.

$$H_{rr} = f(\phi_{\iota}, Vz, AzN)$$
where:

$$\phi_{\iota} \equiv \text{Initial Roll Angle}$$
$$Vz \equiv \text{Barometric Vertical Velocity}$$
$$AzN \equiv \text{Normal Acceleration}$$

The GPWS Algorithm assumes that after a CFIT warning is recognized, if the aircraft is banked, the bank angle will be removed prior to the onset of G and cancellation of terrain closure. If the aircraft is banked less than 10 degrees, the resulting altitude loss increment computed within this section is 0 feet. The reason for this is that the thrust vector is only marginally reduced in the vertical axis and the pilot will likely brings wings level as collective is pulled. Between 10 and 60 degrees of bank, both the roll rates and the altitude loss estimates increase approximately linearly.

The third element of the altitude loss computation determines the altitude that would be lost during the aircraft's descent recovery from its current G-load to the targeted recovery G-load at a pre-determined G-onset rate. All avionics inputs (altitudes, attitude, airspeeds, and G-loading) are used for the descent recovery computations. Velocities and accelerations in x, y, and z are maintained. Contributions from the underlying terrain trend are integrated into the altitude loss estimate at this point using a common, ground tangent plane, co-ordinate system. The net affect is that the GPWS is projecting ahead of the aircraft not only the aircraft's flight path, but also the underlying terrain slope. It is a combination of both the in-air and underlying terrain trend that results in a final altitude loss estimate due to descent recovery (H_{dr}).

$$H_{dr} = f(IAS, TAS, Vz, TC, \theta, AzN, AzN_T, AzN_R)$$
Where:

$$IAS \equiv \text{Indicated Airspeed}$$
$$TAS \equiv \text{True Airspeed}$$
$$Vz \equiv \text{Barometric Vertical Velocity}$$
$$TC \equiv \text{Terrain Closure Rate}$$
$$\theta \equiv \text{Pitch Attitude}$$
$$AzN \equiv \text{Normal Acceleration}$$
$$AzN_T \equiv \text{Target G for Recovery}$$
$$AzN_R \equiv \text{G-Onset Rate}$$

Both the AzN_T and the AzN_R values used for a specific iteration are determined according to the specific aircraft's type and as a function of IAS and Vz.

Descent or dive recovery computations begin immediately following the response time interval and should be coincident with the pilot moving the flight and/or engine controls. The AzN starts to measurably increase to the target-G load and stabilizes at the sustained G level for the aircraft. The altitude loss iteration ends when all terrain closure has been cancelled. In order to keep the altitude loss estimates independent of the aircraft's gross weight and the density altitude, target-G and G-onset rates are selected such that they are achievable over the expected range of operation for the aircraft. For certain heavy lift aircraft (CH-53E) where the target-G was determined not to be achievable in all cases, a takeoff gross weight computation was made and more conservative parameters were used when necessary. Actual flight test results have shown that variations in the G-Onset rate and Target-G due to gross weight and power available had a minimal impact on the altitude loss estimates. This was due to the fact that much of the energy used to initiate a recovery comes from the inertial energy stored in the rotor system.

GPWS WARNINGS AND FLIGHT STATE DETERMINATION

One problem when implementing a GPWS system for military attack/assault helicopters is to determine the criteria for issuing a CFIT warning, but a more difficult problem is the determination of when not to give warnings. The fundamental philosophy is that the system should talk to the pilot only in an emergency, not during a deck edge crossing, landing, or standard low altitude maneuver. In order to accomplish the objective of limiting warnings to specific stages of flight a sophisticated "Flight State Machine" is maintained, which knows what the aircraft is doing at all times. The GPWS identifies different states that the aircraft is in and arms specific warnings in particular states. The GPWS employs a proprietary algorithm to recognize the preflight, takeoff, climbout, flight, landing, touchdown, and autorotation states. The specific criteria used for state transitions are defined by the type of aircraft in which the GPWS is installed. For the H-53 series and the CH-46E, differences exist for the transitions to the landing and autorotation states.

The GPWS altitude loss computations and predictive CFIT warning capability allow the aircraft, in effect, to define the transition criteria for the flight-to-landing state. The difference between a safe landing approach and a potential CFIT accident is defined by the dynamics of the aircraft and the underlying terrain. As the helicopter approaches the ground to hover or land, terrain closure is being cancelled, torque is increasing, airspeed is decreasing, and the pitch attitude is changing. The predicted altitude loss for the aircraft is decreasing and approaching zero. In other words, the normal predictive algorithm calculations are able to distinguish between an unintentional collision with the ground and a landing activity. The algorithm allows the landing state criteria to be very low to the ground – 40 feet AGL and IAS less than 60 knots and gear down, if the gear is retractable.

It was learned during flight test that the landing state criteria initially used successfully for the H-53 series aircraft was not totally satisfactory for the CH-46E. A significant difference existed in how the much lighter CH-46E was operated lower and faster to the ground. The CH-46E routinely approached its landing area passing through 40 feet AGL at 80 knots or more. Using the landing criteria originally established during H-53 flight testing, a CFIT warning was generated – a nuisance warning to the pilots. To solve this problem, a modification was made for the CH-46E to have, in addition to the original landing state criteria, a high landing state that used pitch attitude in order to determine that the aircraft was executing an aggressive approach and was intentionally retarding its closure rate. The ultimate GPWS challenge was to identify low level aggressive flight that could result in a CFIT from an aggressive landing maneuver. The final decision on the specific landing state criteria for military helicopters will always be a tradeoff between providing CFIT warning protection versus an acceptable nuisance alarm rate.

Using the GPWS to assist the pilot during an autorotation maneuver and not add confusion to the situation dictated that the GPWS predictive CFIT warning be inhibited. During this maneuver situational awareness should not be an issue and the autorotation will always terminate in ground contact through a landing or slow air taxi in the case of a practice autorotation. The H-53 and CH-46E autorotation state is defined using torque and rate of descent combinations specific to the aircraft's dynamics during an autorotation. Non-predictive, pilot selectable warnings, are armed for the CH-46E; gear and tail warnings are armed for the H-53's.

Other GPWS Functions

In addition to the predictive CFIT warning, the system provides protection in several other areas. One of the most important is protection for altitude loss after takeoff. This is designed to protect aircraft from flying into the water after taking off from a ship or platform over the water, especially at night. The system arms a moving or follow-up Minimum Recovery Altitude (MRA) when the aircraft passes through 40 ft AGL climbing or crossing the edge of a deck. The MRA is initially set to 20 ft, and a "PULL UP, PULL UP" warning is issued if the aircraft descends below this altitude. The MRA will stay at 20 ft until the aircraft ascends above 50 ft. Then as the aircraft climbs, the MRA will maintain 30 ft beneath the aircraft up to its maximum value of 50 ft. If the aircraft descends, the MRA will stay at its highest value, and if the aircraft breaks the MRA, a "PULL UP, PULL UP" warning will be given. This state will be active for the first minute after takeoff or until the aircraft reaches 250 ft AGL, which ever occurs first. The predictive CFIT warning remains active, however, does not provide the added safety margin required for this critical phase of

flight - especially during a low dynamic, shallow, descent to the water. The timeout value and the altitudes for this state were chosen so as to provide sufficient protection for shipboard operations while not interfering with other mission maneuvers, such as a pick up of an external load.

The remaining GPWS warnings are issued when the aircraft penetrates certain fixed altitudes and configuration parameters.

A descent below the low altitude warning setting on the radar altimeter indicator results in a "ALTITUDE" warning. Other than its obvious value as a safety of flight feature, this function can also be utilized as a pilot cueing device. Applications range from informing the pilot when he is at the desired altitude to deploy embarked troops via fastrope, or when an attached firebucket is at the proper depth to be filled with fire retardant water from a dunking source.

For retractable gear aircraft, a gear-up landing warning is available. The warning conditions are based on the criteria of radar altitude less than 150 ft AGL and airspeeds less than 60 KIAS. The warning consists of the aural warning "GEAR GEAR" and is repeated every 3 seconds until the condition causing the warning no longer exists or if the existing landing gear warning inhibit push button is pressed.

The tailstrike warning is a function of the aircraft's geometry, altitude, rate of descent, pitch, and pitch attitude. The aural warning is "TAIL".

The bank angle warning is issued when the aircraft exceeds an aircraft specific roll attitude. This limit is based on aircraft performance and the geometry where the radar altimeter sensor becomes ineffective. The bank angle warning function provides an additional situational awareness cueing in the event the pilot or aircrew is experiencing vertigo or disorientation. The aural warning is "BANK ANGLE BANK ANGLE".

Deviations below the ILS glideslope warning cause a "GLIDESLOPE" warning when the limits defined in the current FAA specification are exceeded. Aural warnings are repeated every 3 seconds until the glideslope is reacquired.

It should be noted that during flight test visual warning indications, especially for the predictive CFIT warning, provided no additional benefit over the aural ICS warnings. The time required to identify a visual warning and translate it into a recovery action took too long. The aural cues provided a much faster response to a CFIT

warning. Therefore, visual indications were relegated to a secondary panel or device and their purpose became an indicator whether a warning was no longer active and re-armed. Also to be noted is the frequency of aural warnings. Except for the gear and below glideslope warnings, individual warning conditions result in a single aural warning output. The reason for this was to not overload the pilots with redundant information and create additional distraction in the cockpit.

Flight Test and System Validation

Flight and system validation techniques centered around four primary objectives:

1. Confirm correct operations of all functions
2. Optimize Predicted Altitude Loss warnings for individual aircraft performance characteristics
3. Eliminate or minimize to an acceptable threshold the number of false or nuisance cues
4. Ensure no interference with existing aircraft systems

Confirmation of the proper operational functions of the system were carried out by flying the helicopter into the state where the warning would be issued. This was accomplished in a safe and controlled manner for all of the system's functions. In order to test the excessive descent rate or terrain closure functions in a safe manner, the system was tricked with a false hard deck safety buffer of either 500 ft or 1000 ft above the actual ground level. The first portion of the test was flown over water to provide a constant terrain elevation. The aircraft was flown at various rates of descent, angle of bank attitudes, and airspeed combinations to confirm whether the aircraft would recover by the simulated hard deck once the warning was issued. When recovery warnings were issued too high (potential for nuisance warnings) or too low (penetration of the hard deck), adjustments were made to the aircraft's performance parameters within the algorithm. Once the algorithm was optimized for the individual aircraft performance characteristics using the simulated hard deck method, subsequent tests were flown at more realistic altitudes over actual terrain. For the subsequent tests the aircraft was flown at a constant altitude (MSL) flight path to cross over the crest of a 10-15

degree rising terrain slope at 50 to 150 ft AGL, shown in Figure 3. With a 75 ft simulated hard deck inserted into the system, this test confirmed the system would issue an effective warning based on excessively rising terrain. With the 75 ft hard deck removed, the test proved the system would not issue a nuisance warning as the aircraft safely cleared the underlying terrain.
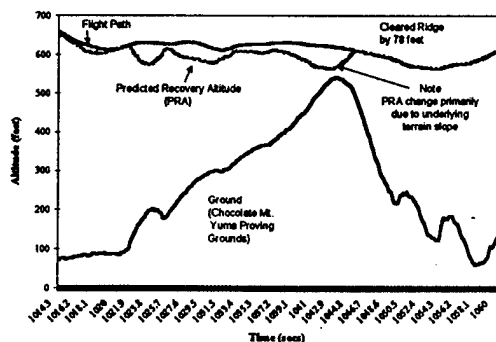

Figure 3 - Flight Into Rising Terrain

Other flight profiles within the normal operating spectrum of each aircraft's mission were flown to confirm the absence of nuisance warnings at critical flight stages. These flight profiles included shipboard landings, confined area landings, and terrain following low level flight. An extensive electromagnetic compatibility and vulnerability test was also conducted to eliminate system hazards due to the electromagnetic environment in which the system would operate.

Conclusions

Flight test results revealed that a GPWS could be fitted for each aircraft tested, which provided enhanced protection against CFIT while not interfering with the aircraft's primary mission. Attractive features of this system are that it takes advantage of existing aircraft sensors, the compact size and low additional weight of the processor has minimal effect on the airframe on which it is installed. By the fact that the system's predictive algorithm is optimized for the performance characteristics of individual aircraft, aircrew can be assured that warnings will be both timely and appropriate. The real success of this system will be judged over time not only by the reduction of CFIT mishaps, but on the absence of nuisance warnings which would decrease aircrew confidence in the system. The idea is that if all goes well, no GPWS warning will ever be sounded. However, if a warning is issued, the pilot should never have reason to question its validity, only to initiate immediate recovery action to avoid CFIT.

Acknowledgments

References

[1] Joint Services Review Committee (JSRC) report on GPWS for Rotary Wing Aircraft, September, 1990.
[2] Chief of Naval Operations "Naval Aviation Policy on Aircraft Safety System Avionics", Ser N88F/8U659710, 12 June 1998.